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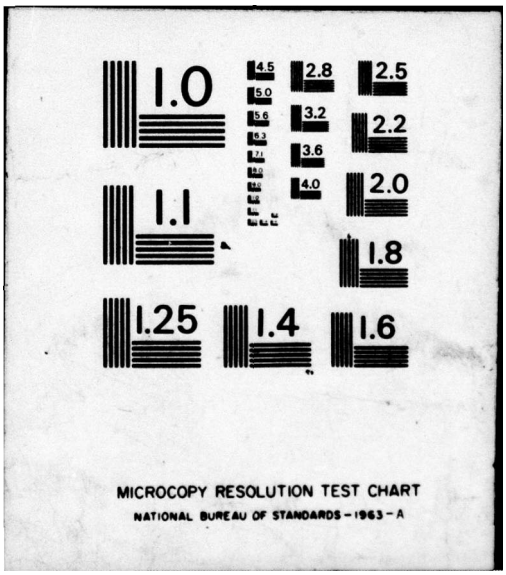
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ABSTRACTS

1976 AFOSR CONTRACTORS MEETING ON UNCONFINED DETONATIONS AND OTHER EXPLOSION RELATED RESEARCH (1976)

Held at

AF ARMAMENT LABORATORY (AFATL)
EGLIN AFB, FLORIDA

on

13-14 DECEMBER 1976.

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IGNITION	DETONATION	HOMOGENEOUS COMBUSTION
DEFLAGRATION	EXPLOSION	HETEROGENEOUS COMBUSTION
FLAME EXTINGUISHMENT	FUEL AIR EXPLOSIONS	
COMBUSTION	SUPERSONIC COMBUSTION	
CUMBUSTION INSTABILITY	PARTICLE DYNAMICS	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report consists of a collection of abstracts of the numerous research progress reports given by AFOSR contractors and of invited papers from other governmental agencies and CONUS and European contractors. These papers presented over a three day period composed the 1976 annual contractor's meeting on combustion dynamics associated with fuel-air explosion phenomena. The principal investigators and their organizational association are also identified.

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1976 AFOSR CONTRACTORS MEETING
ON
UNCONFINED DETONATIONS AND OTHER EXPLOSION RELATED RESEARCH
13-14 DECEMBER 1976
AF ARMAMENT LABORATORY (AFATL)
EGLIN AFB, FLORIDA

Monday 13 Dec 76

8:30-9:00	Bus pick up and transport to Bldg 1 AFATL - Eglin AFB	Ramada Inn Fort Walton Beach (Hotel chosen to accommodate attendees)
9:00-9:30	Official Registration	AFATL-Bldg 1
9:30-9:40	Welcome - AFOSR	
9:40-9:50	Welcome - Military Host	ADTC/DL
9:50-9:55	Morning Chairman	Bernard T. Wolfson/AFPSR Aerospace Sciences Directorate
9:55-10:25	Status of Distributed FAE-II Development	Capt. Ron Fry/AFATL and J. Bowen, Naval Weapons Center, China Lake, California.
10:25-10:40	COFFEE BREAK	
10:40-11:10	Research Program on Conventional Weapons at AFATL Introduction Research in Gun Propellant Combustion Research in Conventional Weapon Aerodynamics Research on Solid Detonations & Blast Waves	W. Dittrich/AFATL B. Moy/AFATL D. Daniels & C. Matthews/AFATL To be selected/AFATL
11:10-11:40	Studies Related to Fuel-Air Explosions at AFATL	J. Foster, AFATL
11:40-12:10	Cloud Initiation in FAE and Target Response to Blast Waves	L. Josephson, Naval Weapons Center China Lake, California
12:10-13:30	LUNCH - Bus to Eglin Officer's Club	
13:30-13:35	Afternoon Chairman	G. Parsons/AFATL
13:35-14-05	Experimental and Theoretical Modeling of Fuel-Air Detonations and Current Army Knowledge Overview	N. Slagg and B. Fishburn Picatinny Arsenal
14:05-14:35	Initiation, Acceleration, Stability and Limits of Detonation	H. Wagner and W. Jost, University of Göttingen, Germany
14:35-15:05	Gasdynamics of Combustion and Explosions in Unconfined Reactive Media	A. K. Oppenheim, University of California-Berkeley
15:05-15:40	COFFEE BREAK	
15:40-16:10	Transition from Deflagration to Detonation in Unconfined Fuel-Air Clouds	R. Edse, Ohio State University
16:10-16:30	Bus to Motel	
18:30-21:00	Social Activity (Informal Attire)	

Tuesday, 14 Dec. 1976

8:00-8:20	Bus pick up and transport to Bldg. 1	Ramada Motel
8:20-8:25	Morning Chairman	To be announced
8:25-8:55	Source Requirements for Direct Initiation of Unconfined Fuel-Air Detonations	J. Lee, et al: McGill University Montreal, Canada
8:55-9:25	Direct Initiation of Detonation and Blast Effects in Unconfined Explosions	R. Strehlow and H. O. Barthel Univ. of Illinois-Urbana
9:25-9:55	Mechanisms of Initiation and Propagation of Detonations Through a Non-Uniform Unconfined Two-Phase Reactive Cloud	J. A. Nicholls, et al: University of Michigan
9:55-10:25	Two-Phase Detonations and Variable Energy Blast Waves	E.K. Dabora, University of Connecticut
10:25-10:40	COFFEE BREAK	
10:40-11:10	Study of Instability Mechanisms Related to Detonation Wave Structure, Stability and Initiation Requirements	T.Y. Toong, Massachusetts Institute of Technology
11:10-11:40	Chemical Sensitization of FAE Clouds	G. Von Elbe, Atlantic Research
11:40-12:10	Pyrophoric Initiation of FAE	M. Summerfield and M. Varney-Princeton Combustion Labs
12:10-13:30	LUNCH	
13:30-13:35	Afternoon Chairman	Bernard T. Wolfson/AFOSR
13:35-14:05	Dice-FAE Analysis of Fuel Dispersal and Detonation from a Fuel-Air Explosive Device	M. Rosenblatt, Calif. Research & Tech. Inc.
14:05-14:35	D-ARPA Fuel Air Explosion Program	E. Blase, D-ARPA, Washington, D.C.
14:35-15:05	Concepts for Improved Fuel-Air Explosions	R. T. Sedgwich, Systems, Science and Software, La Jolla, Calif.
15:05-15:15	Goals for Large Unconfined Fuel-Air Explosions	Capt. G. J. Goss Defense Nuclear Agency, Wash. D.C.
15:15-16:10	Application of Fuel-Air Explosions to Nuclear Blast Effects	R. W. Oliver, McMillian Sciences Association, Arlington, Virginia
16:10-16:3	AFOSR Executive Session	AFOSR Contractors and Grantees only
16:35	ADJOURN	
16:40	Bus to Ramada Inn	

STATUS OF DISTRIBUTED FAE DEVELOPMENT

by

Capt. Ron Fry, AFATL, and J. Bowen
Naval Weapons Center, China Lake, California

ABSTRACT NOT AVAILABLE

RESEARCH PROGRAM ON CONVENTIONAL WEAPONS AT AFATL

by

W. Dittrich, AFATL

ABSTRACT NOT AVAILABLE

RESEARCH IN GUN PROPELLANT COMBUSTION

by

B. Moy, AFATL

ABSTRACT NOT AVAILABLE

RESEARCH IN CONVENTIONAL WEAPON AERODYNAMICS

by

D. Daniels and C. Matthews, AFATL

ABSTRACT NOT AVAILABLE

STUDIES RELATED TO FUEL-AIR EXPLOSIONS AT AFATL

by

J. Foster, AFATL

ABSTRACT NOT AVAILABLE

EXPERIMENTAL AND THEORETICAL MODELING OF FUEL-AIR DETONATIONS AND CURRENT ARMY KNOWLEDGE OVERVIEW

by

N. Slagg and B. Fishburn, Pictinny Arsenal

ABSTRACT NOT AVAILABLE

CLOUD INITIATION IN FAE AND TARGET RESPONSE TO BLAST WAVES

by

L. Josephson
Naval Weapons Center, China Lake, California

ABSTRACT NOT AVAILABLE

INITIATION, ACCELERATION, STABILITY AND LIMITS OF DETONATION

by

H. Wagner and W. Jost
University of Gottingen, Germany

ABSTRACT NOT AVAILABLE

Department of Mechanical Engineering
McGill University
Montreal, Quebec
Canada

Abstract

Experiments on Volumetric Initiation

by

J.H. Lee and R. Knystautas

Our AFOSR program deals with initiation and propagation mechanisms of unconfined gaseous detonations. Its aims are to provide quantitative answers to the following questions: Given a particular fuel-air mixture, can it detonate? If so, what is the initiation energy? What are the limits of detonability? Can transition from flame to detonation occur in the mixture? What are the mechanisms of volumetric initiation of detonations? Apart from the combustion aspects, our program also investigates the blast effects associated with fuel-air explosives. In this meeting we shall discuss our recent work on volumetric initiation only.

In general, detonation initiation is achieved via a localized energy source (e.g., HE charge) and the combustion wave spreads from the ignition source to consume the cloud. If an infinitely large number of ignition sources are distributed within the cloud, then the entire volume explodes "spontaneously". This mode of initiation is referred to as volumetric initiation. The initiation sources can be free radicals produced via a primary reaction as the fuel is dispersed into the atmosphere. With a sufficient concentration of free radicals in the fuel-air cloud, then the secondary reaction of the fuel with oxygen will be initiated. Volumetric initiation is simpler and more reliable when applied to F.A.E. weapons than the conventional blast initiation scheme. For

distances greater than about one cloud radius, the air blast from a volumetric initiated explosion differs little from that of a central initiated detonation. Preliminary experiments using exotic compounds have been reported by Von Elbe and Walker at the last AFOSR FAE meeting. Due to the difficulties in the handling of these compounds, it has not been possible to make detailed observations of the volumetric initiation phenomena. However, pressure records do suggest that some sort of multiple spherical detonation has occured inside the volume.

In an effort to elucidate the fundamental mechanisms involved, a simpler system is studied at McGill. The free radicals are generated via photo-dissociation by the irradiation of the explosive mixture with a strong pulse of UV light. For the simple H_2-Cl_2 system, free radicals of Cl can readily be generated via photo-dissociation $Cl_2 + h\nu \rightarrow 2Cl$ in the 2500 Å to 4000°A region. For obtaining the atomic oxygen for hydrocarbon-air explosions a sensitizer such as NO_2 must be used since O_2 absorbs well only in the far UV region. Hence, by irradiating a detonating gas with an intense flash, volumetric initiation can readily be achieved in a wide variety of fuel-oxidizers. The photo-dissociation being the primary reaction to produce the required radical concentration to initiate the secondary main reaction itself.

From our experiments, it can be observed that detonation is formed within the volume after an induction period ranging from a few tens of microseconds in H_2-Cl_2 mixtures to a millisecond in unsensitized C_2H_2-O_2 mixtures, in the central pressure range of 20 to 100 torr. The induction period depends weakly on initial pressures, flash energy (once the threshold is exceeded) as well as the sensitizer (i.e., NO_2) concentrations for hydrocarbon-oxygen mixtures. Pressure measurements indicated that fully established detonations are formed inside the irradiated volume. There exists a minimum volume in

which no sharp pressure rise is observed and combustion proceeds as in the normal mode of constant volume explosion in a closed chamber. Photographic schlieren photographs revealed that detonations are formed inside the volume in a manner similar to that under the critical conditions for the onset of detonations using other modes of initiation (transition or direct initiation). This suggests the universal nature of the phenomena of the onset of detonation. The experiments also indicate that the number of explosion centers in the volume depends on the free radical concentration. Under critical conditions, only one explosion center is usually observed at the termination of the induction period.

Direct Initiation of Detonation and Blast Effects from Unconfined Fuel Air Explosives

Roger A. Strehlow
Harold O. Barthel

University of Illinois,
at Urbana-Champaign

This program includes both an experimental and theoretical effort. In the experimental effort, we are measuring delays to explosion and rates of heat release in the explosion using a reflected shock technique. Two systems are being studied. These are (1) The effects of inhibitors and promotors on the propane-air system, and (2) The propylene oxide-oxygen-nitrogen system.

In this technique the department's 101.6 x 381mm shock tube is being used to produce reflected shocks in the explosive mixtures. A streak schlieren interferometer with a laser light source is being used to monitor the density field near the back wall, and a Kistler pressure gauge is being used to monitor pressure rise due to heat release. The combination of rate of pressure rise and rate of density decrease after the induction period is used to calculate the effective rate of heat release due to the homogenous explosion of the fuel-air mixture. Results will be presented.

In the theoretical program we are using non-ideal blast wave flow fields that are generated by the modified CLOUD program, and studying the delay to explosion in the gas surrounding the source region using realistic assumptions about reaction kinetics in that region. This allows us to determine a minimum energy for direct initiation as a function of the non-ideality of the source. Two types of non-ideal sources are being investigated at the present time. These are (1) Bursting sphere, and (2) Ramp addition of energy. The primary reason for choosing these is that the blast calculations for these cases were available. We anticipate that as we proceed in this study the effects of other types of source non-ideality will be investigated in a systematic manner.

GRANT AFOSR-73-2524

Mechanism of Initiation and Propagation of Detonation through a Non-Uniform Unconfined Heterogeneous Cloud

J. A. Nicholls, M. Sichel
The University of Michigan

The objective of our Eglin AFB supported research has been to study and elucidate some of the more important fundamental aspects of fuel-air explosions. Emphasis has been placed on heterogeneous clouds although gaseous clouds have also been studied. Towards this end a cylindrically shaped fuel-air cloud has been modeled for experimental studies through use of a pie shaped detonation chamber. For heterogeneous studies liquid fuel drops, all of the same size, can be produced and distributed uniformly throughout the chamber. Blast wave initiation of detonation is achieved through use of a blasting cap and a charge of condensed explosive at the "center of the cloud".

A photographic study was made to determine the degree to which the blast initiated shocks or detonations approached a true cylindrical wave. Shadowgraphs of the shock waves, or detonation waves, immediately beyond the exit of the chamber are shown. In general, the wave shape is very close to cylindrical. In some cases, debris, presumably from the the initiating charge, is observed ahead of the wave.

The use of 147 needles to generate the liquid drops for

the heterogeneous case makes it possible to study the effects of a variation in fuel/air ratio with radius. Preliminary results are shown where fuel "gaps" in the cloud were studied. Varying number of needles were inactivated in a zone near the critical radius and, in another case, in a zone downstream where detonation has been established. Some results are presented which indicate the extent of weakening, or termination, of detonation as a function of the size of the fuel gap.

Theoretical studies of the blast initiations process have been conducted. The Zel'dovich criterion for initiation is that the blast energy must be such that when the pressure ratio across the shock front has decayed to the Chapman-Jouguet value, the distance travelled by the shock must be at least of the order of the reaction zone thickness. A modified version of this criterion has been expressed in quantitative form, and used to determine a dimensionless initiation energy using the stoichiometric value as a reference. Good agreement was found between this simple theory and initiation energies for MAPP air and C_2H_2-O_2 mixtures measured at three different laboratories. The theory also predicts the variation of initiation energy with ambient pressure.

The research program described terminated and at this writing our only work in fuel-air explosions is related to the LNG spill problem.

VARIABLE ENERGY BLAST WAVES AND TWO-PHASE DETONATIONS*

by

E. K. Dabora

and

E. T. Pitkin

In certain cases of spray detonations, photographic evidence has indicated that blast waves around the burning droplets form part of the mechanism for the continued propagation of the detonation wave. The blast waves are due to fast energy addition resulting from fuel and gaseous oxidizer reaction, as well as to an effective mass addition to the gaseous medium surrounding the droplet. It is reasoned that during the time scale pertinent to spray detonations, both energy release and mass addition are time dependent.

Accordingly, some attention was devoted to the characterization of blast waves with energy inputs of the form

$$E_\alpha = W_\alpha t^\beta$$

where W_α is a constant of proportionality and β can take on values of $0 \leq \beta \leq \alpha + 1$ (with $\alpha = 0,1,2$ for plane, cylindrical and spherical geometries). In the past, approximate solutions to the blast wave trajectories and numerical solutions of blast trajectory and flow field for the case $\beta = 1$, $\alpha = 2$ were developed and the latter was compared to the flow field generated by a focused laser.

Recently, we have used the perturbation technique of Freeman (which was confined to $\beta = 1$, $\alpha = 1$) to obtain solutions for the general case. Graphs of typical shock trajectories and flow field density, pressure and velocity variations will be presented. In addition, the influence of β on the partition of energy between thermal and kinetic within the blast wave will be

shown.

It is felt that with the above solutions a good handle on the variable energy blast wave exists at present. Thus, some attention was devoted to the mass addition aspect. Accordingly, some experiments on the fragmentation and vaporization of liquid droplets subjected to a high power laser were conducted. Typical photographs of the resulting phenomena will be presented and discussed.

*Work support by ARO Grant # DAAG29-76-G0142

ABSTRACT

Experimental Investigation of Acoustic-Kinetic Interactions in Non-Equilibrium H_2-Cl_2 Reactions*

by

Jean-Pierre Patureau, Tau-Yi Toong and Charles A. Garris

Department of Mechanical Engineering

Massachusetts Institute of Technology

It has long been recognized that the coupling between chemical kinetics and acoustic wave propagation may be instrumental in the growth of small pressure disturbances which eventually lead to the non-linear, large-amplitude instabilities often observed in practice. Considerable insight into this phenomenon has already been obtained in several theoretical studies [1, 2, 3, 4]. In one of them [1], sound propagation in an infinite, irreversibly reacting medium was considered for the case of a simple one-step reaction with Arrhenius kinetics. Substantial amplification of the pressure fluctuations, as high as 300 to 400% under certain conditions, was predicted for exothermic reactions. Based on this type of analysis, extensive theoretical results have been obtained, especially in regard to sound scattering and acoustic energy considerations [4]. Yet, to the knowledge of the authors, no systematic experimental investigation of this phenomenon has been reported so far; hence the motivation for this work.

---

* Reference [5].

Experiments of sound propagation in a non-equilibrium hydrogen-chlorine reacting mixture were conducted in a 5.5 m-long, 8 cm-diameter Pyrex tube. The photochemical reaction between H_2 and Cl_2 is initiated by UV radiation incident onto the premixed, homogeneous reactive mixture. The overall reaction is measured by monitoring the quantity of UV light absorbed by molecular chlorine and the mean temperature of the gas phase by means of a resistance thermometer. Sound waves are generated at one end of the tube by means of a shaker-piston arrangement, in the form of a 2-cycle burst of a given frequency and monitored by means of several microphones strategically placed along the tube. The incident burst subsequently reflects back and forth at both ends of the tube and as a result, one is able to examine a specific acoustic wave during a time interval as long as 0.2 to 0.3 second, before its amplitude reaches the noise level due to sound absorption.

Amplification of the sound pressure fluctuations due to acoustic-kinetic coupling was consistently observed throughout this investigation at different acoustic frequencies and for different H_2-Cl_2-Ar mixture compositions. Analysis of the experimental results shows that the observed rate of amplification is typically three times larger than what would be expected from simple consideration of conservation of acoustic energy, thus indicating that the contribution of the acoustic-kinetic coupling effect to the net sound amplification is very significant (total amplifications of up to 60% of the initial sound amplitude were commonly observed over the sound residence

time-interval). Within experimental error and also within the uncertainty attributed to the determination of the overall Arrhenius parameters m and β (determined for each test by fitting the observed chlorine concentration and mean temperature histories to an Arrhenius expression), it is found that the instantaneous rate of sound pressure amplification depends on the instantaneous experimental value of the expression

$$\frac{1}{2\gamma T_o(t)} \frac{dT_o}{dt}(t) \left\{ m + \frac{\beta(\gamma-1)}{T_o(t)/T_{o,in}} + \gamma \right\}$$

, regardless of the sound frequency and mixture composition or pressure. This is in agreement with the theoretical predictions of the quasi-steady model. This result is also consistent with the observation that the present experimental investigations was conducted in the quasi-steady interaction regime.

References

[1] Toong, T. Y., Arbeau, P., Garris, C. A., Patureau, J.-P., Fifteenth Symposium (International) on Combustion, p. 87, The Combustion Institute, 1975.

[2] Gilbert, R. G., Hahn, N. S., Ortoleva, P. J., and Ross, J., J. Chem. Phys., 57, 2672, 1972.

[3] Gilbert, R. G., Ortoleva, P. J., and Ross, J., J. Chem. Phys., 58, 3625, 1973.

[4] Garris, C. A., Toong, T. Y., and Patureau, J. P., Acta Astronautica, 2, 981, 1975.

[5] Patureau, J.-P., Toong, T. Y., and Garris, C. A., presented at the Sixteenth Symposium (International) on Combustion, in press.

CHEMICAL SENSITIZATION OF FAE CLOUDS

by

G. Von Elbe, Atlantic Research

ABSTRACT NOT AVAILABLE

AN ABSTRACT

Prepared for the 1976 AFOSR Contractors Meeting
December 13-14, 1976
Eglin Air Force Base,
Florida

PYROPHORIC INITIATION OF FUEL AIR EXPLOSIONS

by
K.P. Hall, A.M. Varney, L.S. Ingram, and M. Summerfield
Princeton Combustion Laboratories
A Division of
Flow Research, Incorporated
Based on Contract No. FO8635-76-C0182
January 22, 1976 to June 30, 1976
Sponsored by AFATL
Eglin Air Force Base

The motivation of the short experimental investigation reported herein was to determine the feasibility of initiating fuel-air detonations by release of a small quantity of pyrophoric fuel in the midst of a dispersed fuel/air cloud. If successful, this method could be developed as an alternative to the well-known technique using a grenade-type cloud detonator. For certain applications, the pyrophoric initiation method would have practical advantages. (See Figure 1.)

As originally planned the investigation was laid out on a twelve month schedule and comprised three phases. The first phase was a broad search, first in the literature and then in laboratory tests, for candidate pyrophoric substances. Foremost in the list of desired properties was prompt runaway to flame (a few milliseconds) and a normal vapor pressure in the right range for effective dispersion and good stoichiometry. The second phase was to comprise a theoretical study of the conditions that might lead to transition from near-isochoric explosion of the pyrophoric/air region in the cloud to a full detonation wave across the rest of the FAE cloud. (See figure 2). This was seen at the outset as the heart of the problem. The third and final phase of the planned year's effort was a series of trials, first at laboratory scale and then in field scale, to determine whether such transition would indeed occur.

Unfortunately, funds did not materialize for the continuation of the project beyond the five-month point, and so a quickly revised program of lab and field experiments with a few readily obtainable pyrophoric substances was decided upon, in consultation with AFATL. It was hoped, that with luck, DDT transition would occur and thus demonstrate the feasibility of the idea. Unfortunately, although flame acceleration was observed in some of the full scale trials, DDT did not occur. The main conclusion reached was that, indeed, the question of achieving transition from a central pyrophoric/air explosion to full detonation is the main question, and as expected, it is not a simple matter. It would be regrettable if the failure to achieve transition in the quick tests conducted in the closing weeks of this suddenly shortened project were taken to mean that the idea is faulty.

The problem of achieving transition can be described as follows. When a pyrophoric-air mixture explodes, at best isochorically, the highest pressure produced will be less than 10 atmospheres and probably only about 5 atmospheres, depending on the rapidity of the reaction, the heat release per unit mass of fuel, and the stoichiometric ratio at the point of runaway. Such pressures are too low to set off a full detonation. Obviously, a transition zone is needed around the explosion to permit acceleration of the explosion wave to the higher pressure range of true detonation.

Acceleration may be expected in any case, as a result of increasing turbulence with distance, but to speed up the transition, sensitization of the transition zone by admixture with some of the

same pyrophoric material would be helpful. As remarked above, this kind of tailoring of the distribution of pyrophoric material is not a simple matter. Also, the rate of reaction has to be taken into account, and so measurements of such rates would be needed in order to properly design an optimum distribution of the pyrophoric material in the initiation region.

The search for candidate pyrophoric materials at the outset of the project turned up a list that exceeded 100 substances, some of them gases, some liquids at room temperature, and some powdered solids. (The list in Figure 3 is representative.) Because of the time constraints imposed by the shortened project, only a limited number of candidate substances was screened, using a simplified qualitative laboratory procedure. These were not the most desirable materials from the standpoint of the criteria established at the beginning of the project; they were, however, readily available. The screening test results suggested that, of the tested compounds, the most reactive was a mixture of trimethyl aluminum (TMA) and triethyl aluminum (TEA), liquid aluminum alkyls of modest vapor pressure. The evaluation was based on total luminosity emitted when a premeasured quantity of the liquid was atomized by means of a metered amount of high pressure nitrogen. (See Figure 4 for comparative data, and Figure 5-1 for the test configuration.) The explosion time for the TMA/TEA mixture was of the order of 50 msec., rather long for the intended purpose, but the best available in the truncated study. A series of further experiments was performed using variations on this mixture, as illustrated in Figures 5-2. through Figure 5-5, the purpose being simply to make sure that the injection scheme would work on a large scale test and that a fast flame would indeed ensue. Figures 5-2 through 5-4 represent experiments conducted at PCL; Figure 5-5 illustrates a bag test, as performed at Eglin AFB.

The results of the small-scale experiments with TMA/TEA may be summarized as follows:

(a) A 0.2 ml quantity of 1:1 TMA/TEA, injected into the atmosphere from the apparatus of Figure 5-1 by sudden rupture of the burst disc supporting the pool of pyrophoric, inflamed with a loud report and a bright visible flash.

(b) A similar quantity injected into an enclosed reactor (400 ml volume filled with a stoichiometric quantity of air at one atmosphere, as in Figure 5-2) failed to generate even 1 atm. of pressure rise. Apparently wall quenching halted the reaction at an early stage.

(c) A similar quantity injected into a 5-foot long pipe shock tube (3-inch pipe) filled

with a MAPP-air mixture, (Figure 5-3.) initiated a deflagration wave in the pipe. (The mylar closure which was glued to the downstream end of the tube blew off, and a one-foot long flame shot out.)

(d) Two plastic refuse bags ("Lawn and Leaf" size) were taped mouth-to-mouth and inflated with a MAPP-air mixture. (Figure 5-4) Injection of 0.2 ml of the TMA/TEA blend into the inflated bag initiated a deflagration which destroyed the bag.

(e) Finally, tests were made with another version of the apparatus of Figure 5-1 scaled up in size to deliver 2.0 ml of pyrophoric fuel at one shot. This larger injector was checked out at PCL (and later tested exhaustively at Eglin AFB).

Upon completion of the various experiments described above, a cooperative test program involving both PCL and Eglin AFB personnel was undertaken on one of the Eglin test ranges. Using a pair of 2.0 ml size injectors mounted to operate in parallel, an assortment of operating parameters was examined either by injection directly into air (15 tests) or by initiating a bag explosion in a typical Eglin AFB test bag like that of Figure 5-5 (4 tests). The following conditions seemed to produce the best results:

Metered volume of atomizing gas (driver gas)	47 ml/injector
Driver gas pressure	1000 psi
Driver gas composition	100% oxygen
Pyrophoric volume (in one injector)	1.80 ml
Pyrophoric composition	1 to 3 mix of TMA/TEA
FAE composition	7% by volume propylene oxide in air
Second injector	Contained 2.10 ml of liquid propylene oxide

Injectors adjusted so that the two outlet sprays mixed.

Four deflagrations were produced with pyrophoric fuels in four attempts, using large scale test bags (4 ft. X 4 ft. X 20 ft. long) containing propylene oxide-air. The deflagration initiated under the above described conditions was the strongest (Figure 6).

The wave velocity for this test (deduced from high speed movies) was 76 meters/sec. (Mach 0.23)

The main conclusions of the project are:

1. The concept of pyrophoric initiation is still worth investigating.

2. The criteria for a satisfactory pyrophoric fuel are high heat release, fast reaction with air, and a vapor pressure in the right stoichiometric range.

3. There is a broad array of substances and combinations of substances that may be used as pyrophorics, nearly all of them untested.

4. The question of transition from explosion to detonation is the central one. It needs both theoretical and experimental study.

DICE-FAE ANALYSIS OF FUEL DISPERSAL AND DETONATION FROM A FUEL-AIR-EXPLOSIVE DEVICE

by

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Using the DICE-FAE code, a numerical solution was generated of both the dispersal and detonation phases for a BLU-73 liquid Fuel-Air-Explosive device. DICE-FAE is a two-dimensional, implicit, Eulerian, finite difference code which treats fuel-air mixtures, fuel droplet break-up, fuel phase changes, and fuel-air detonation dynamics. The fuel droplets flow through the air and interact with the air through drag and heat exchange mechanisms.

The cloud dispersal analysis started with initial conditions representing the fuel mass and burster products just after canister break-up. The FAE detonation analysis commenced with the calculated dispersed cloud fuel-air characteristics and with second event initiation by a centrally-located explosive charge.

Detailed comparisons from the DICE-FAE results and experimental data have not been completed, but the final calculated cloud dimensions and peak detonation pressures appear reasonable. The computational results also provide a detailed prediction in terms of space and time of the fuel concentrations during the dispersal phase and of the pressures and temperatures during the detonation phase.

D-ARPA FUEL AIR EXPLOSION PROGRAM

by

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ABSTRACT NOT AVAILABLE

CONCEPTS FOR IMPROVED FUEL-AIR EXPLOSIONS

by

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During the past year we have been working in the area of FAE under DARPA sponsorship. The primary objectives of our ongoing FAE program include advancing FAE technology in such areas as fuel dissemination and cloud detonation and developing concepts for large area (diameter $\geq$ 100 M) coverage. Our investigations to date have given rise to the following conclusions.

- FAE clouds with low H/D (height-to-diameter) ratios ($\sim$ 0.1) deliver a minimum effective impulse over a greater range than do clouds whose H/D ratios are close to 1.
- Significant focusing can be obtained by forming clouds with cylindrical or conical voids.
- Significant concentrated blast enhancement can be obtained by employing imploding detonation fronts.
- The generation of P-I plots and the superimposition of these plots on various structural damage curves indicate that cloud shaping and implosive detonation can result in improved performance against hard targets (armored personnel carriers) at short range and relatively soft targets (trucks and personnel) at long range.
- At certain ranges and against certain targets, large FAE devices are competitive with low yield nuclear weapons.
- Techniques for disseminating solid aluminum powder using high pressure nozzles and central burster charges have been developed and demonstrated. In the latter case, dissemination without preignition of the cloud was demonstrated.
- Measured pressures and arrival times within an unconfined cloud of aluminum powder indicate that unconfined detonation has been achieved.

GOALS FOR LARGE UNCONTAINED FUEL-AIR EXPLOSIVES

by

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It is desired to have a reusable facility capable of simulating nuclear airblast phenomena. The facility should have the capability of simulating the effects of up to a 1KT nuclear air burst and should generate highly repeatable waveforms. The facility could be used to verify calculational prediction techniques and to conduct effects testing on various military equipment.

As applied to fuel-air technology, these goals present needs to conduct detailed predictive calculations on various fuel dispersal and detonation schemes. If indicated by these results, a pilot facility with building-block capability could be constructed.

APPLICATION OF FUEL-AIR EXPLOSIONS TO NUCLEAR BLAST EFFECTS

by

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ABSTRACT NOT AVAILABLE

DYNAMICS OF EXPLOSIONS IN FUEL-AIR MIXTURES

by
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The objective of our studies is the acquisition of knowledge on gasdynamic properties of explosively reacting combustion systems. In particular, this includes: (a) experimental investigation of strong ignition limit and its chemico-dynamic features, (b) numerical analysis of flow fields generated by exothermic processes of combustion, and (c) evaluation of combustion-driven blast waves in gaseous media. Results of the work contribute directly to the understanding of FAE in the areas of initiation, gasdynamic and chemico-kinetic processes occurring within the cloud, and blast waves generated in the inert atmosphere surrounding the cloud.

The program of research involves experimental investigation, analytical study, and the development of computational techniques. The experiments are performed using a shock tube of rectangular 1-1/4" x 1-3/4" cross-section with observations made, primarily behind the reflected shock, by means of ultra-high speed cinematographic laser schlieren and shear-interferometry,as well as pressure transducer measurements. Analytical studies are concerned with the determination of salient gasdynamic features of blast waves, as they are affected by various conditions at which energy is deposited in the exploding medium, its thermodynamic properties, and transport processes. Computational techniques are developed for the evaluation of non-steady flow fields associated with pressure waves generated by accelerating flames.

The specific purpose of the experiments carried out last year was to investigate the effect of hydrogen as an explosion-promoting agent in the combustion of hydrocarbon mixtures. This was accomplished by determining experimentally chemical induction times and strong ignition limits in argon-diluted mixtures of methane, hydrogen and oxygen.

Experimental conditions covered a temperature range of 1100°K - 2500°K and pressures varying from 1 atm. to 3 atm. The induction time was measured directly from pressure transducer records, while the strong ignition limits were determined by evaluating the wave front trajectories from recorded pressure history, supported by evidence provided by cinematographic laser-schlieren records.

In order to cover the full range of conditions over 500 experimental runs had to be made. The data are now in the process of correlation.

Our analytical studies included the following topics: self-similar blast waves of variable energy deposited at the front, self-similar blast waves of variable energy supplied by a piston (the latter to be regarded as representing the interface between the products of the exploding medium and the surrounding atmosphere which is set in motion by the explosion), an investigation of the structure of blast waves in liquids, and of the effects of some "real gas" properties and of transport phenomena on blast waves. Of particular significance to our future work in this field is the development of a novel analytical technique, which we call the Phase Space Method, for the treatment of non-self-similar blast waves.

The numerical technique under development is set in Eulerian coordinates. It is based on a finite difference scheme of second order in accuracy which was initially developed by R. W. MacCormack at the NASA AMES Research Center. It uses the floating shock fitting method introduced by G. Moretti of GASEL and the Polytechnic Institute of New York as modified by M. D. Salas of the NASA Langley Research Center. All the interactions between gasdynamic discontinuities, that is shocks, interfaces, and flame fronts treated as deflagrations, are computed exactly, as solutions of appropriate Riemann problems, by a set of subroutines. The algorthm is now being employed to determine the evolution of non-steady flow fields driven by a flame that is caused to accelerate by imposing a finite increase upon its initially steady propagation speed. The ultimate purpose of this study is to evaluate the "explosivity" of a fuel-air cloud, that is the ability of a flame in such a cloud to accelerate to detonation.

TRANSITION FROM DEFLAGRATION TO DETONATION IN UNCONFINED FUEL-AIR MIXTURES

by

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During the last year four different aspects of fuel-air explosions have been investigated.

1. The effect of initial temperature of the combustible gas mixtures on the detonation induction distances in hydrogen-air mixtures has been studied. This investigation was undertaken to determine whether low initial temperatures enhance the formation of detonation waves in fuel-air mixtures as it had been observed for fuel-oxygen mixtures in this laboratory previously. The experiments were carried out in a 6.4 m long, 5 cm inner diameter cylindrical tube with hydrogen-air mixtures at an initial pressure of 1 atmosphere and initial temperatures ranging from 123 K to 300 K. The results of the measurements showed that the induction distances are greatly reduced as the temperature of the unburned gas is lowered. To elucidate the mechanism governing the transition from deflagration to detonation, the normal burning speeds of hydrogen-air mixtures were also determined at temperatures from 123 K to 300 K and even up to 784 K. According to these measurements the flame speeds of hydrogen-air mixtures are proportional to the square of the absolute temperature of the unburned gas. Because of this large decrease of the rate of propagation of the deflagration wave, the reduction of the induction distance with decreasing temperature must be attributed to the increase in density of the unburned gas which at low temperature is high enough to cause the initial combustion to occur at nearly constant volume. Experiments with clouds of droplets of liquid air and liquid methane have been planned but not executed as yet because of the unknown hazards involved in carrying out such experiments. To assess the contribution of turbulence on the reduction of the induction distance an apparatus has been designed and constructed to study the effect of mechanically introduced turbulence on the transition of a deflagration wave to a detonation wave in fuel-air mixtures.

2. Flame propagation rates and wave pressures resulting from explosions of practically unconfined clouds of hydrogen-air

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mixtures were determined in various cloud sizes. The objective of this research is to determine whether a combustion wave initiated in unconfined clouds of fuel-air mixtures would accelerate sufficiently to form a stable detonation wave. The measurements were made in 1, 2, and 4 m^3 polyethylene bags. The flame speeds were derived from photographs taken with a 35 mm FASTAX camera and the pressure measurements were made with KISTLER KIC 717A pressure microphones. The results of these experiments indicate that both the flame speeds and the wave pressures increase quite significantly with the volume of the hydrogen-air cloud. Larger volumes of the explosive mixture are needed to determine whether the acceleration continues and is sufficient to transform the deflagration into a detonation. However, because of safety considerations it is not possible to make experiments with larger clouds at this laboratory. With the observations on hand attempts will be made to develop a mathematical model for predicting the transition from deflagration to detonation in three dimensions. However, data obtained from experiment, with larger clouds may be needed before a meaningful theory can be developed.

3. To ascertain the effect of buoyancy on the transition from deflagration to detonation pre-detonation phenomena were observed in vertical tubes. In one series of experiments the combustible gas mixtures were ignited at the top of the tube and in another the flames were started at the bottom. Measurements to date indicate that the wave pressures are practically the same for both series of these experiments.

4. Experiments have been initiated to study the mechanism of quenching of deflagration and detonation waves in fuel-air mixtures. The following topics are to be investigated in detail:

a) the influence of flame speed on the effectiveness of the arresting material.

b) the effects of type of material, pore size, and path length on quenching.

c) re-ignition of the unburned gas by the hot combustion gas of the successfully quenched flame zone.

d) the use of catalytic flame inhibitors as surface coatings in arrestors.

e) the mechanism of the dissipation of shock waves in arrestors.

f) the nature of the quenching process: removal of thermal energy from the flame and/or influence on the reaction kinetics of the flame.